RESERVOIR SEDIMENTATION STUDIES TO DETERMINE VARIABILITY OF PHOSPHORUS DEPOSITION IN SELECTED KANSAS WATERSHEDS

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Abstract: *Phosphorus is an important nutrient because it is the principal limiting factor for primary biotic production in most freshwater environments. It also is an important water-quality constituent because excessive phosphorus concentrations in reservoirs can cause algal growth that may result in taste-and-odor problems in water supplies (eutrophication). In Kansas, reservoirs are the primary source of drinking water for many municipalities and rural water districts, and taste-and-odor problems could be a major concern.*

Phosphorus in Kansas reservoirs primarily is of nonpoint-source origin and may be related to fertilizer application and livestock production in contributing watersheds. Because phosphorus is transported primarily in the particulate phase, analysis of fluvially transported sediment that has accumulated in Kansas reservoirs can provide information on historical phosphorus concentrations and yields that may cause accelerated eutrophication.

For the purpose of comparing phosphorus transport throughout Kansas, four reservoirs in watersheds with different topography, soils, underlying geology, land use, and climate were selected for analysis of reservoir bottom sediment. Bottom-sediment cores were collected from Webster Reservoir in north-central Kansas, Cheney Reservoir in south-central Kansas, and Tuttle Creek and Hillsdale Lakes in northeastern Kansas. The cores were analyzed for total phosphorus, bulk density, and selected constituents and properties. The chemical data were combined with reservoir bathymetry, which showed changes in reservoir sediment volume, to estimate mean annual sediment and phosphorus yields for each of the four reservoir watersheds.

Estimated mean annual sediment yields varied considerably among the four reservoir watersheds and ranged from 0.03 acre-foot per square mile per year in the Webster Reservoir watershed to 0.97 acre-foot per square mile per year in the Hillsdale Lake watershed. Estimated phosphorus yields ranged from 0.04 pound per acre per year in the Webster Reservoir watershed to 1.7 pounds per acre per year in the Hillsdale Lake watershed.

Reservoir sediment studies in Kansas have been useful in reconstructing historical trends in water quality that can be used as a measure of the effectiveness of best-management practices implemented throughout the watersheds. With the addition of bathymetric surveys and the inclusion of additional reservoirs, sediment studies also can be used to establish baselines for estimating historical loading of phosphorus and other constituents in future water-quality assessments throughout Kansas.

INTRODUCTION

Phosphorus is an essential element for plant growth, and its addition to cropland has become important in the maintenance of profitable agricultural production in the United States. However, excessive phosphorus inputs from municipal, industrial, and residential sources as well as from agriculture can have detrimental effects on adjacent or downgradient aquatic systems by increasing the biological productivity of surface water. The resultant eutrophication may cause taste-and-odor problems for water suppliers, degrade habitat for aquatic life, and discourage recreational use of the affected water body.

Remedial efforts during the past several years have been focused on reducing water contaminants from nonpoint sources because it is believed that point sources, for the most part, have been identified and controlled where it is cost effective to do so. Nonpoint sources of water contamination, such as from agricultural application of phosphorus, are difficult to identify, and remediation efforts are difficult and expensive to implement. It also can be many years before any improvements are seen in water quality once remediation efforts begin.

Phosphorus, along with many other constituents, adsorbs to fine-grained sediment particles, primarily silt and clay, and also is associated with fine organic material. In stream channels and reservoirs, these particles can be transported great distances, finally settling into the quiet, deeper areas of reservoirs where they accumulate in sediment. Because reservoir sediment acts as an integrator of activities within the watershed (Mau and Christensen, 2000), sampling the reservoir bottom sediment can be very informative in determining trends in phosphorus use throughout the watershed.

The U.S. Geological Survey (USGS), in cooperation with various local, State, and Federal government agencies, began investigating Kansas reservoir bottom sediment in 1995. The studies were multifaceted, looking at sediment deposition along with selected chemical constituents in sediment cores from reservoirs located in various geologic, topographic, and climatic landscape regions throughout Kansas. The results of four reservoir sedimentation studies that examined the variability of phosphorus deposition for the Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake watersheds (fig. 1) are presented in this paper. The purpose of this paper is to: (1) describe phosphorus yields since reservoir impoundment, and (2) discuss probable causes for differences in phosphorus yields among the reservoirs and their respective watersheds. The four reservoirs described were sampled during the period October 1, 1995, through September 30, 1999.

<u>Setting:</u> The Webster Reservoir watershed is located in north-central Kansas and has a contributing-drainage area of about 1,150 square miles (table 1). Land use primarily is agricultural, with about 57 percent used for cropland and 37 percent used for pastureland (Bureau of Reclamation, 1984, p. 9). Topography within the watershed is flat to gently rolling, with narrow, shallow valleys and low relief. The soils consist of sand, clay, loess, or silt.

The Cheney Reservoir watershed, located in south-central Kansas, is approximately 933 square miles. Land use primarily is agricultural, with about 52 percent of the watershed in cropland and the balance consisting of pastureland, forest cover, and small urban areas. Topography within the watershed generally is flat to gently sloping hills. The soils are classified as clayey loam in the uplands to sand or sandy loam in the low-lying areas.

Tuttle Creek Lake has the largest watershed and surface area of the four reservoirs, with a contributing-drainage area of about 9,600 square miles (table 1) in southeastern Nebraska and northeastern Kansas. About 72 percent of the watershed is cropland, and nearly 16 percent is pastureland. The topography is reflected in generally smooth plains consisting of sand, gravel, silt, and clay in the Nebraska section and areas of greater local relief underlain by shale, sandstone, limestone, and fluvial and eolian deposits in the Kansas section of the watershed (Pope, 1995, p. 4).

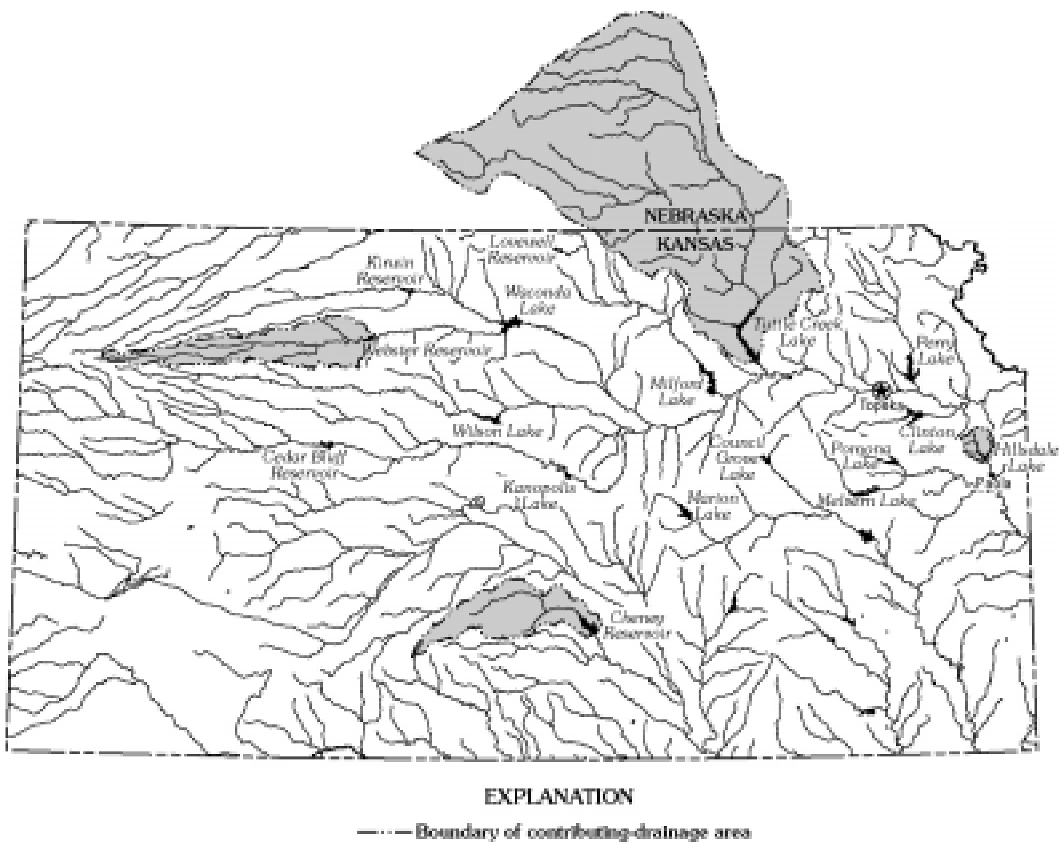

Figure 1. Location of four reservoir watersheds in Kansas.

The smallest of the four reservoir watersheds described in this paper, the Hillsdale Lake watershed, has a contributing-drainage area of about 144 square miles and is located in northeastern Kansas. Croplands constitute about 35 percent of the land use, and the balance consists mostly of pastureland and forest cover. The watershed consists of gently rolling uplands, with hilly areas along the streams, and is underlain by shale and limestone (O'Connor, 1971).

Precipitation varies considerably among the four reservoirs studied. Long-term mean annual precipitation is about 24 inches at Webster Reservoir compared to about 27 inches at Cheney Reservoir. The long-term mean annual precipitation at Tuttle Creek Lake is about 32 inches and about 41 inches at Hillsdale Lake (measured 5 miles south at Paola, Kansas). Long-term means were based on a period of record from 1961-90 (National Oceanic and Atmospheric Administration, 1998). Consideration should be given to the fact that precipitation varies throughout each watershed. In general, precipitation increases west to east in Kansas and Nebraska; therefore, the precipitation at Webster Reservoir and Tuttle Creek Lake is likely to be greater than in their respective watersheds.

Methods: The methods used to estimate total phosphorus deposition since reservoir impoundment included both bathymetric surveying (mapping of the reservoir bottom) and reservoir bottom-sediment coring. Bathymetric surveys have been done infrequently at the four reservoirs making it infeasible to calculate an accurate annual volume and rate of phosphorus deposition. Therefore, a mean annual phosphorus yield was estimated by dividing the total accumulated sediment volume by watershed drainage area and by the time period since reservoir impoundment.

Bathymetric surveys were done at each reservoir along existing range lines established by either the U.S. Army Corps of Engineers or the U.S. Department of Interior's Bureau of Reclamation (BOR). Global-positioning-system (GPS) technology was used to record the geographic location of the boat on the reservoir, and a fathometer system was used to determine the depth to the reservoir bed. The data were digitally recorded and used to compare the original pre-reservoir, range-line topographic data to the most recent bathymetric data.

Dry-mass estimates of sediment deposition into the reservoirs required determining reservoir bottom-sediment bulk density. This was done by collecting reservoir bottom-sediment cores using a gravity corer (fig. 2). The gravity corer was fitted with cylindrical, transparent plastic liners with a 2.63-inch inside diameter that collected and stored the sediment-core sample. Sediment-core samples were collected from several locations in each reservoir to obtain representative samples. The core samples were processed at the USGS laboratory in Lawrence, Kansas, and analyzed for percentage of sand and fines (particles less than 0.062 millimeter in diameter; silt and clay), bulk density, and percentage of moisture, according to methods presented in Guy (1969). Sediment samples from three of the reservoirs also were submitted to the USGS National Water-Quality Laboratory in Denver, Colorado, for analysis of total phosphorus and other chemical constituents. Sediment samples from Webster Reservoir were analyzed for total phosphorus and other chemical constituents by the BOR laboratory in Bismarck, North Dakota, using both U.S. Environmental Protection Agency (1997) and USGS methods (Fishman and Friedman, 1989).

Table 1. Comparison of reservoir and watershed characteristics for Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake, Kansas

Reservoir or lake	Date of impoundment	Contributing-drainage area (square miles)	Original conservation pool storage (acre-feet)	Land use[1]		Long-term mean annual precipitation[2] (inches)
				Percentage of basin in pastureland	Percentage of basin in cropland	
Webster	1956	1,150	72,000	37	57	24
Cheney	1965	933	152,000	<48	52	27
Tuttle Creek	1962	9,600	425,000	16	72	32
Hillsdale	1981	144	68,000	50	35	41

[1]Land-use percentages from Nebraska Resources Commission (1983), Bureau of Reclamation (1984), Kansas Applied Remote Sensing Program (1993), Kansas Department of Agriculture and U.S. Department of Agriculture (1997), and Putnam (1997).

[2]Long-term mean annual precipitation is based on 1961-90 data from the National Oceanic and Atmospheric Administration (1998).

VARIABILITY OF PHOSPHORUS DEPOSITION

Estimated mean annual phosphorus yields to the reservoir watersheds varied from 0.04 pound per acre per year for the Webster Reservoir watershed to 1.7 pounds per acre per year for the Hillsdale Lake watershed (table 2). The relation between phosphorus concentration and percentage of fines in the sediment has been documented. At Cheney Reservoir, for example, a correlation coefficient, r, of 0.96 was determined for the relation between concentrations of phosphorus in sediment and percentage of fines in sediment (Pope, 1998). On a per-square-mile-of-watershed basis, the largest mean annual phosphorus yield was estimated for the Hillsdale Lake watershed where the largest estimated mean annual sediment yield occurred. The Hillsdale Lake watershed also receives the most annual precipitation and, in conjunction with the relatively hilly topography and substantial percentage of cropland, may be prone to more erosion losses per square mile than the other reservoir watersheds in this study. The Webster Reservoir watershed, in comparison, experiences significantly less precipitation, a mean annual total of 24 inches, and has a more gently sloping topography. There also are more than 800 small farm ponds in the Webster Reservoir watershed that serve as sediment and water traps, reducing streamflow and suspended sediment transport to the reservoir (Bureau of Reclamation, 1984, p. 37).

Figure 2. Bottom-sediment cores were collected with a gravity corer mounted on a pontoon boat. The corer is lowered to a designated distance above the sediment and allowed to free fall to penetrate through the entire thickness of reservoir bottom sediment.

Historical trends of chemical constituents in reservoir bottom sediment over time can be an important measure of the effectiveness of best-management practices (BMP's) as well as the accumulation effect of phosphorus. However, reservoir-bottom-sediment layers can undergo mixing during storms or periods of flooding, or phosphorus may be converted from the sediment phase to the dissolved phase. Mixing and conversion can create difficulties in the analysis of trends.

Substantial conversion of phosphorus in sediment to dissolved phosphorus can occur at the sediment/water interface (Lung and Larson, 1995). In Kansas reservoirs, burial of sediment is relatively rapid, which may restrict the effect of the conversion process in altering the vertical distribution of phosphorus. However, as previously stated, the conversion of phosphorus from the sediment to the dissolved phase may affect the interpretation of shallow sediment layers.

To determine whether bottom sediment had been disturbed physically, selected sediment cores were analyzed for cesium-137. Cesium-137, a by-product of thermonuclear-weapons testing of the 1950's and early 1960's, is widely dispersed by atmospheric deposition and is sorbed to soil particles (primarily clay). Detectable cesium-137 concentrations in sediment began about 1952 and peaked about 1964, followed by a steady decline in concentrations (Holmes, 1998).

Because of its wide dispersal, cesium-137 can be used as a method to age-date sediment layers (McHenry and Ritchie, 1981; Ritchie and McHenry, 1990; Callender, 1993). Three of the four reservoirs in this study—Webster, Cheney, and Tuttle Creek—were analyzed for cesium-137 by sectioning selected sediment cores. Webster Reservoir and Tuttle Creek Lake were built prior to 1964, and the cesium-137 peak concentrations are evident in the sediment profile from Tuttle Creek Lake

Table 2. Estimated total sediment deposition and sediment and phosphorus yields to Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake, Kansas

Reservoir or lake	Total sediment deposition (acre-feet)	Mean annual sediment yield (acre-feet per square mile of watershed per year)	Percentage of sediment deposition, in-channel	Mean annual phosphorus yield to reservoir (pounds per acre per year)
Webster	1,330	0.03	81	0.04
Cheney	7,800	.25	10	.53
Tuttle Creek	114,000	.31	34	.41
Hillsdale	2,100	.97	56	1.7

(fig. 3). Cheney Reservoir was built after the cesium-137 peak concentration; therefore, only the tail (decreasing cesium-137 concentration) following the peak is visible in the reservoir bottom sediment from Cheney.

The sharp peak and relatively uniform decrease of cesium-137 concentrations in the sediment (fig. 3) suggest that the sediment was deposited in the reservoirs and not resuspended or mixed annually. Therefore, evaluation of trends in phosphorus deposition over time can be done with some confidence. Although cesium-137 concentration analysis was not done on the reservoir bottom sediment at Hillsdale Lake, total phosphorus concentrations did not show any trend with depth. Total phosphorus concentrations in selected bottom-sediment cores from Webster Reservoir and Tuttle Creek Lake also did not show any trends with depth. However, the evidence from Cheney Reservoir indicates that total phosphorus concentrations in the more recent sediment are larger than in the deeper, older sediment (fig. 4). The correlation coefficient, r, between total phosphorus concentrations and depth within the sediment cores from Cheney Reservoir ranged from 0.71 to 0.95, indicating a significant relation between the two variables (Pope, 1998). This implies that phosphorus use in the Cheney Reservoir watershed has increased in the past 33 years, probably as a result of increased agricultural activities.

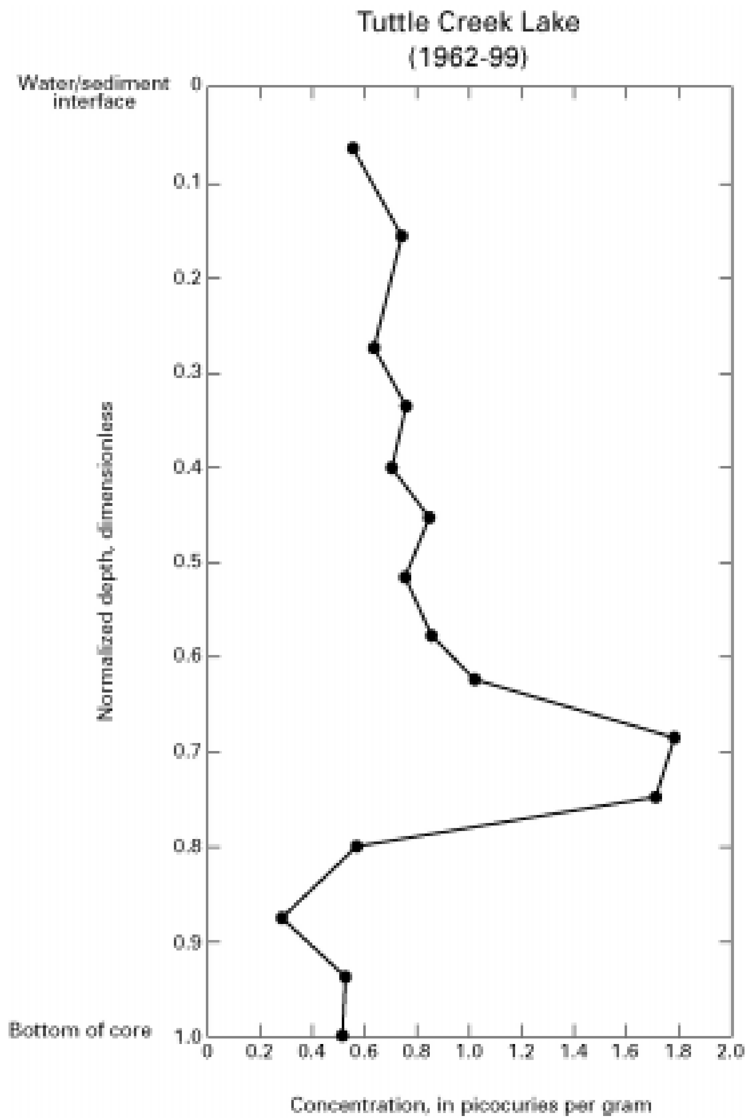

Figure 3. Concentrations of cesium-137 in sediment profile from Tuttle Creek Lake.

Both Spearman's rho and Kendall's tau correlation analyses were done on the total phosphorus concentrations in Webster Reservoir to evaluate whether a statistical relation existed between sediment depth within the core and total phosphorus concentration (Christensen, 1999). Both analyses are nonparametric procedures that are based on ranks, but Spearman's rho gives more weight to differences between data values ranked farther apart; Kendall's tau is resistant to the effects of extreme values. Results from the two tests indicated that there was no discernible trend for total phosphorus concentrations with depth in the reservoir bottom sediment from Webster Reservoir (Christensen, 1999). Similarly, at Hillsdale Lake, no apparent trend was observed between total phosphorus concentration and depth in the reservoir bottom sediment (Juracek, 1997), and preliminary results from Tuttle Creek Lake indicate that no trend exists (D.P. Mau, USGS, unpublished data on file at the U.S. Geological Survey office in Lawrence, Kansas).

The adsorption of phosphorus to silt and clay particles and the association of phosphorus with fine organic material suggest that phosphorus can be transported farther into the reservoir and deposited in the deeper, less turbulent water, typically near the dam. Larger concentrations of phosphorus, therefore, might be expected in the reservoir bottom sediment near the dam, especially in the in-channel locations which are typically the deepest areas within the reservoir. However, an analysis of bottom-sediment cores from in-channel sites upstream and downstream in the reservoirs provided ambiguous results. There were no in-channel trends in phosphorus concentrations within the

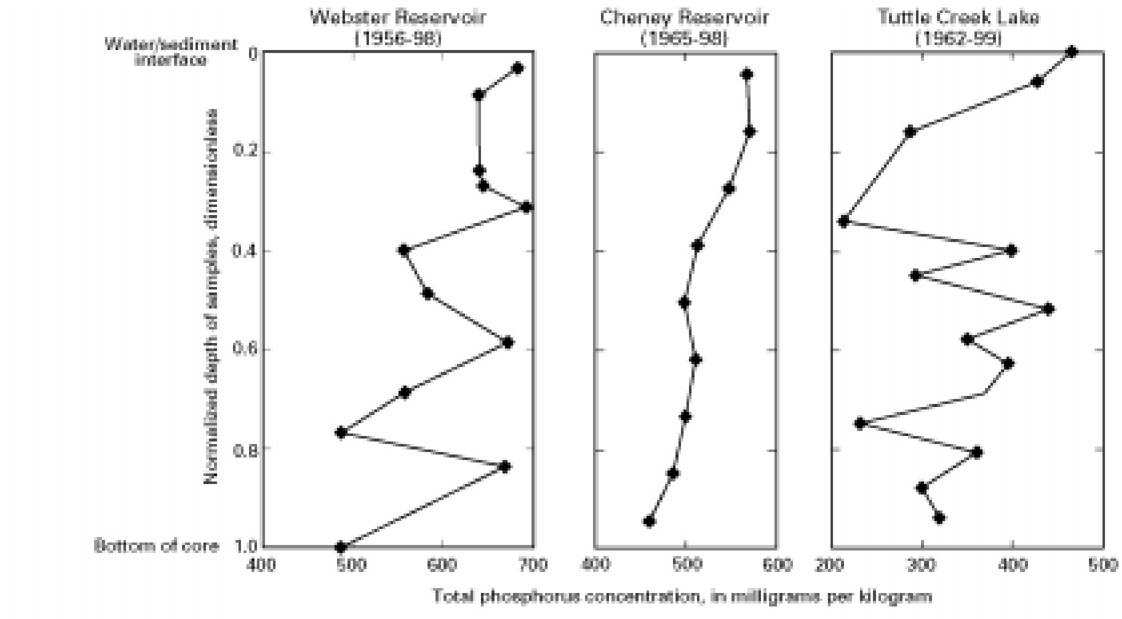

Figure 4. Concentrations of total phosphorus in sediment profiles from Webster Reservoir, Cheney Reservoir, and Tuttle Creek Lake, Kansas.

reservoirs identified at either Webster or Hillsdale (Christensen, 1999; Juracek, 1997). However, trends were apparent at Cheney Reservoir and Tuttle Creek Lake (Pope, 1998; D.P. Mau, unpublished data on file at the U.S. Geological Survey office in Lawrence, Kansas).

The extremely low sediment yield for Webster Reservoir, possibly a result of sediment retention from more than 800 small farm ponds scattered throughout the watershed, in addition to low precipitation, might explain the small phosphorus yield. Hillsdale Lake, in comparison, had the largest phosphorus yield on a per square mile basis. Precipitation in the Hillsdale Lake watershed is the highest among the watersheds of the four reservoirs studied and, along with the substantial relief in topography, suggests an increased transport of sediment and total phosphorus into the reservoir. The lack of any trend in total phosphorus upstream to downstream, or in-channel versus out-of-channel, in Hillsdale Lake is surprising but may be related to the fact that the reservoir is relatively new (completed in 1981) and trends may not have developed yet.

Trends in depositional patterns of total phosphorus upstream to downstream are evident, however, within Cheney Reservoir and to a lesser extent within Tuttle Creek Lake (Pope, 1998; D.P. Mau, USGS, unpublished data on file at the U.S. Geological Survey office in Lawrence, Kansas). Percentage of fines in sediment from Cheney Reservoir was highest near the dam and progressively decreased farther upstream. Phosphorus concentrations showed a similar trend, probably because of the adsorption to fine-grained sediment and association with fine organic material. Tuttle Creek Lake data showed increases in mean phosphorus concentrations upstream to downstream, but concentrations decreased near the dam. The reason for this is unknown but may be related to the hydrodynamics and subsequent turbulence created by water releases from the dam. A low-energy environment, therefore, may not be available near the dam for the smaller particles to be deposited in the bed sediment near the dam.

SUMMARY AND CONCLUSIONS

Bathymetric surveying and sediment coring were used in this study to examine four reservoirs in watersheds with different topography, soils, underlying geology, land use, and climate. The reservoirs are integrators of watershed activities, and therefore, trends in reservoir bottom sediment may be indicative of trends in the watershed. Estimated sediment and phosphorus yields varied considerably among the watersheds.

Mean annual sediment yields ranged from 0.03 acre-foot per square mile per year in the Webster Reservoir watershed to 0.97 acre-foot per square mile per year in the Hillsdale Lake watershed. Estimated phosphorus yields ranged from

0.04 pound per acre per year in the Webster Reservoir watershed to 1.7 pounds per acre per year in the Hillsdale Lake watershed. The largest phosphorus yield was estimated for the Hillsdale Lake watershed, where the largest annual sediment yield occurred. The size of sediment particles also had a strong relation to phosphorus concentrations as documented by the results from Cheney Reservoir. This indicates that the amount and size of sediment particles can be an important factor for phosphorus yield in Kansas reservoirs.

Also important are topography and precipitation in the watersheds. The hilly topography and higher precipitation in the Hillsdale Lake watershed likely caused more erosion and runoff of sediment and increased phosphorus yield to the reservoir. Precipitation is important because watersheds in Kansas that have more precipitation also have a larger sediment yield (Mau and Christensen, 2000).

Finally, land use can be an important factor in the variability of sediment and phosphorus yields. Phosphorus in Kansas reservoirs is mainly of nonpoint-source origin and may be related to the application of fertilizers or the production of livestock. BMP's may decrease the input of phosphorus to reservoirs from these nonpoint sources, and reservoir sediment studies may provide an important indication of BMP effectiveness.

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